Interactions of Small-Scale Physical Mixing Processes with the Structure, Morphology, Bloom Dynamics and Optics of Non-spheroid Phytoplankton

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LONG-TERM GOALS

Our long-term goal is to understand the ecology of phytoplankton inhabiting coastal shelves, upwelling areas, fjords and banks. We are especially interested in ways in which species-specific properties, including colony size and shape (diatoms) and motility (dinoflagellates) interact with physical mixing processes to regulate spatio-temporal distribution patterns. We wish to understand these processes in sufficient detail to be able to predict bloom dynamics, size structure, and the impact of species-specific characteristics of the phytoplankton on ocean optics.

OBJECTIVES

We are steadily accumulating evidence that interactions between physical processes at multiple time and space scales, and the species-specific (e.g. size, shape, motility etc.) properties of diatoms are important factors contributing to phytoplankton distribution, bloom dynamics, particle size structure and optical characteristics in the ocean. Our objectives under current funding are to further develop our conceptual model by addressing several questions:

- do diatoms in addition to *Eucampia zodiacus* (see FY01 report) alter size, shape and/or growth rate in response to the level of turbulence under which they are grown?
- does each species respond in a unique way?
- are the responses shape-specific – *i.e.* do different species belonging to a particular shape category respond to turbulence in a similar fashion?
- does turbulence affect the inherent optical properties of diatoms on a species-specific basis?

APPROACH

We have addressed these questions via a series of laboratory experiments examining the effects of persistent small-scale turbulence on the cell/colony morphology, particle length, growth rate and inherent optical properties of the diatoms *Bacteriastrum hyalinum*, *Chaetoceros debilis* and

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Chaetoceros affinis. All three bear siliceous setae (spines), however the setae of each are arranged in very different 3-dimensional structures (Fig. 1). These results are compared to those from earlier experiments on the helical, but non-spiny taxon *Eucampia zodiacus*.

WORK COMPLETED

We have conducted three replicated experiments each on the effects of persistent turbulence on the diatoms *Bacteriastrum hyalinum, Chaetoceros debilis* and *Chaetoceros affinis*. Analysis of the *B. hyalinum* data is complete. Particle length, growth rate and inherent optical data have been analyzed from the *Chaetoceros* experiments; morphometric analyses are in progress.

RESULTS

<u>Size, morphology and growth rate</u> (Fig. 1): Both particle size (*i.e.* colony length) and growth rate showed species specific responses to persistent small-scale turbulence. The helical taxa *Eucampia zodiacus* and *Chaetoceros debilis* formed many abnormal colonies in the absence of turbulence (control tank) and at our lowest treatment (epsilon ~10^{-8} m^2 sec^{-3}), the longest colonies at levels of 10^{-7} to 10^{-6} m^2 sec^{-3} and formed only very short chains, or pairs of cells at the highest treatments (epsilon~ 10^{-5} to 10^{-3} m^2 sec^{-3}). The growth rate of *E. zodiacus* was enhanced at epsilon levels > 10^{-6} m^2 sec^3, but the differences between the 4 highest treatments were not statistically significant. Growth of *Chaetoceros debilis* was slightly enhanced by increasing turbulence. *Bacteriastrum hyalinum* showed no significant effect on growth rate, and a decrease in particle size only at turbulence levels > 10^{-4} m^2 sec^{-3}. In contrast, turbulence had a dramatic impact on the growth rate of *Chaetoceros affinis*, but no significant effect on particle size.

In terms of particle length and width, *Eucampia zodiacus* was the largest taxon investigated, and its colony length was the most sensitive to turbulence. *Eucampia* cells are essentially “glued” together into colonies with polysaccharide mucous, thus cells separate relatively easily, and without apparent damage. *Chaetoceros debilis* is also a helical taxon, but with hair-like setae (silicified spines) radiating outward from the helix. Although the same general shape as *Eucampia*, its helices are smaller in diameter. Cells of *Chaetoceros* are fused together into chains, and thus cannot simply separate, like those of *Eucampia*. As a result, it maintained longer colonies than *Eucampia* at the mid-ranges of turbulence. The ability of the helix to flex may allow it to withstand greater turbulence without breaking. *Bacteriastrum hyalinum* possesses radial symmetry, and numerous setae, thus it resembles a bottle-brush. Setae density and orientation may function as ‘rebar’, thus ‘structuring’ the surrounding water, and making the colony less susceptible to damage by turbulence. In evidence, of the four taxa, it retained the longest colonies at the highest level of turbulence. However, the trade off is that these same factors may also inhibit the flux of water and nutrients to the surface of the cells: note that turbulence did not have a significant effect on growth rate, and that *B. hyalinum* had the lowest growth rate of the four examined. *Chaetoceros affinis* is normally small in size. It lives at a scale where the viscous forces dominate the inertial forces, thus it experiences linear shear, but not the 3-dimensional forces of turbulence. The setae (spines) of this taxon lie in a single plane, thus the colony is relatively 2-dimensional. Since it is not 3-dimensionally reinforced, it may remain short in length so as to minimize mechanical stress on the colony. Although turbulence had no effect on colony length or morphology, its effect on growth rate was dramatic, presumably because linear shear increased the flux of nutrients to the cell surface. Interestingly, the three taxa that possess setae (siliceous spines) did not exhibit a uniform response to turbulence.

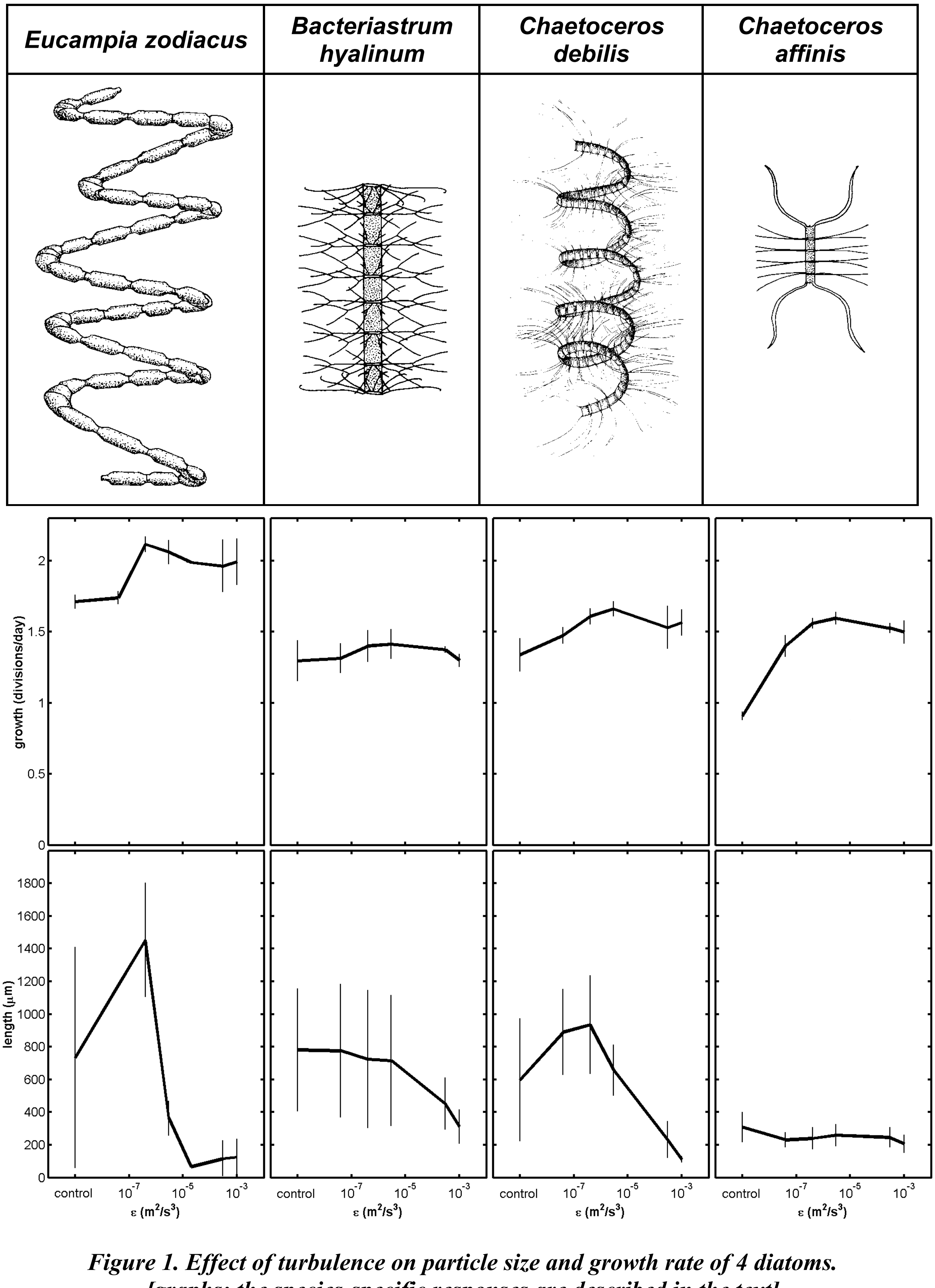
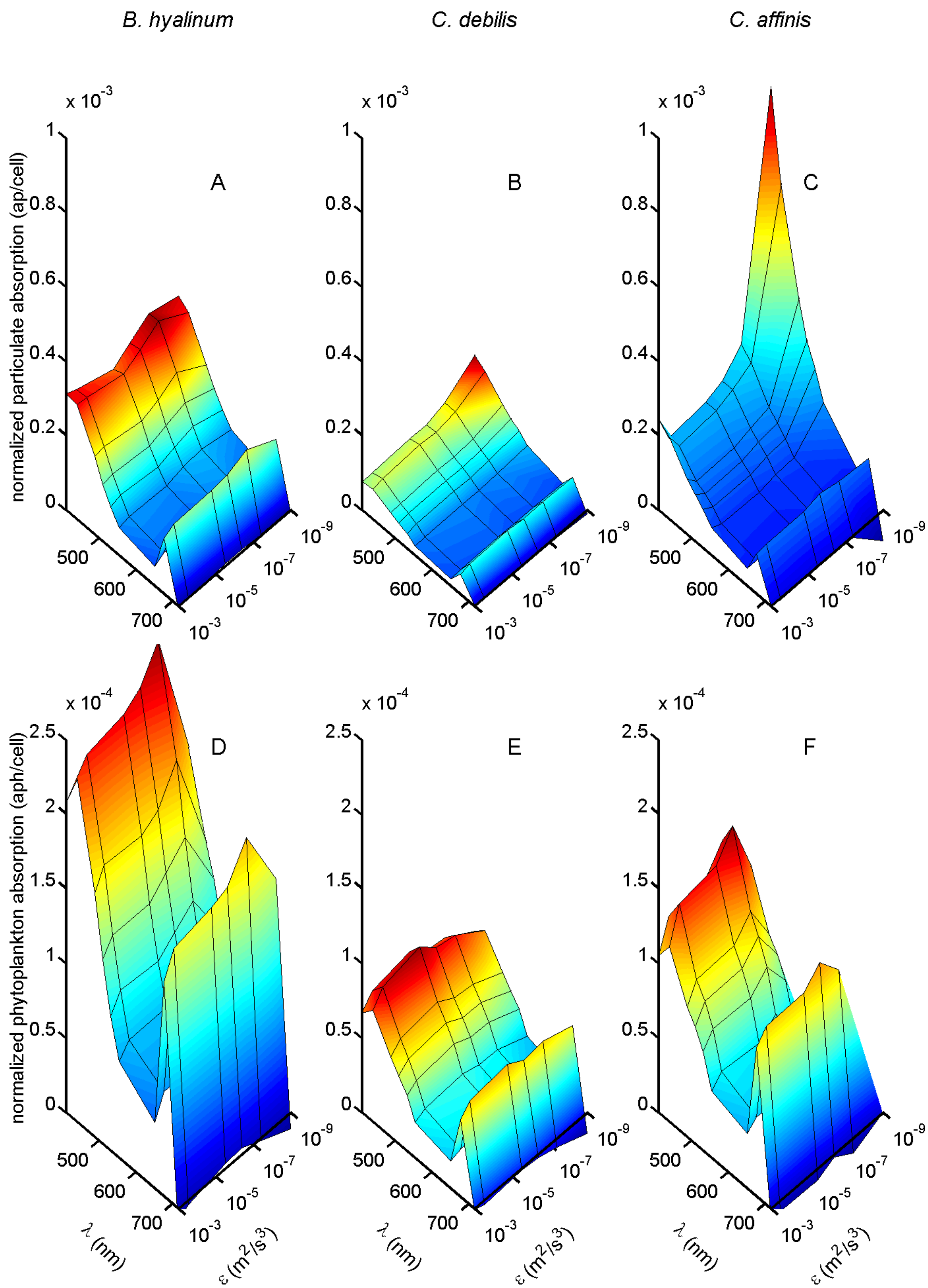


Figure 1. Effect of turbulence on particle size and growth rate of 4 diatoms.
[graphs: the species-specific responses are described in the text]
[drawings illustrate the shape of each taxon]



B. hyalinum
C. debilis
C. affinis
x 10^-3
normalized particulate absorption (ap/cell)
A
B
C
x 10^-4
normalized phytoplankton absorption (aph/cell)
D
E
F
λ (nm)
ε (m²/s³)

Figure 2 (a-f). Inherent optical properties of three diatoms.
[graphs: impact of persistent turbulence on the spectral absorption characteristics of cultures of Bacteriastrum hyalinum (Figs 2a,d), Chaetoceros debilis (Figs 2b,e) and C. affinis (Figs 2c,f). Measurements at the end of the experiments, of spectral absorption by particulate material were normalized by dividing by cell numbers (to remove biomass differences) and plotted versus wavelength (λ) (increasing from left to right along the y axis) and turbulence level (ε) (decreasing from left to right along the x axis) (Figs 2a,b,c). In each case, particulate absorption per cell declined at short wavelengths with increasing turbulence levels. The magnitude of this effect varied with species, with the biggest effects seen in C. affinis (Fig. 2c). Since particulate absorption in these cultures includes absorption by both phytoplankton and biogenic detritus, we calculated spectral absorption by just the phytoplankton (using the methods described by Roesler et al. 1989) and plotted it versus wavelength and turbulence level for the three species (Figs 2d,e,f). Absorption per cell by phytoplankton increased with increasing turbulence from low values in the controls to a maximum at intermediate turbulence levels, then declined at the highest turbulence levels. Although the magnitude of this effect varied with species, the species differences were much less dramatic than for particulate absorption (Figs 2a,b,c).]

<u>Inherent Optical Properties</u> (Fig. 2): Spectral absorption and attenuation of dissolved and particulate material were measured with a WET Labs ac-9 for each turbulence level at the end of the experiments conducted on *Bacteriastrum hyalinum*, *Chaetoceros debilis* and *C. affinis*. Although turbulence had no effect on spectral absorption by dissolved material, it had strong spectral effects on absorption and attenuation by total particulate material (Figs 2a,b,c), biogenic detritus, and phytoplankton alone (Figs 2d,e,f). The magnitude of these effects varied between species, but tended to follow the same pattern as the effects of turbulence on cell growth rates with the largest effects noted in *C. affinis* and the smallest effects in *Bacteriastrum*. These results not only demonstrate that persistent turbulence can affect particle size and growth rates of spiny diatoms, but that turbulence can also affect the inherent optical properties.

IMPACT/APPLICATIONS

In the last two years, we have complimented our investigations into the effects of turbulence on diatom colony size and shape (morphological properties) by obtaining additional information on the effects of small-scale turbulence on growth rates, and inherent optical properties (physiological properties) of chain-forming diatoms. It is obvious that both parameters show species-specific effects related to colony size and morphology. Our results are significant, because they make it clear that:

- Estimations of growth rate from unstirred laboratory batch cultures cannot be applied to the field, because they are not accurate. We must to be able to characterize the turbulent environment in which diatoms are growing before we can expect to predict growth rate.
- Likewise, IOP characterizations from quiescent laboratory batch cultures cannot be extrapolated to the field, because we have demonstrated that these values are strongly dependent on the turbulent environment in which colonies are grown. In the 3 species we studied, the largest deviations were noted between quiescent conditions (characteristic of most batch cultures), and the mid-ranges of turbulence.
- Given our demonstrated, species-specific effects of turbulence on diatom growth rates and IOPs, coupled with the fact that the taxa we examined are known to form blooms, it is essential that we have models which can tell us how the turbulence in the sea changes over time. Our ability to build models

predicting species-specific growth responses, the development of blooms, and the resulting IOPs depends on it!

- An important step towards developing this kind of model is to delineate, and evaluate the characteristics, and species-specific responses to turbulence of the major, functional morphotypes of chain-forming diatoms.

RELATED PROJECTS

We are collaborating with M.S. Twardowski (WET Labs), and J.M. Sullivan & P.L. Donaghay (Donaghay's award N000149510222) in the development of an approach to document the optical characteristics of individual phytoplankton cells and colonies. This work has resulted in proposals to the LOCO DRI Program. We have provided laboratory cultures and data from our experiments to assist in the interpretation of bulk optical field data collected by Donaghay & Sullivan. We are also collaborating with D.V. Holliday (BAE Systems) to document the formation of oxygen bubbles by phytoplankton, and by benthic and episammic microalgal communities.

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